OVERVIEW OF RESEARCH TO DATE

My primary academic interests are developing models for describing changes in populations and communities at broad spatial and temporal scales and to make these models useful and accessible to practitioners and researchers alike by operating within an Open Science framework. Although I would describe myself as a generalist, my research to date can be distilled as: developing and improving methods for identifying changes in ecological populations and communities at broad scales

**I. Research interests overview: synthesis science, quantitative and invasion ecology**

Synthesizing information is integral to the study of ecological systems (Carpenter *et al.*, 2009), and synthesis projects are important in that they emphasize the reuse and integration of disparate data—data which is often expensive and/or difficult to capture. Although I have designed and conduced field studies, my recent research endeavors involve using extant data to understand broad-scale changes in faunal (Burnett & Moulton, 2015; Burnett *et al.*, 2017), floral (Donovan *et al.*, 2018) and algal (Burnett *et al.*, in prep.) populations and communities. Invasions, because they are largely driven by human introductions, are a global phenomenon, lending well to studying biogeography at broad spatial scales. In addition to understanding the relationship between invaders and native species, modern invaded systems provide natural experiment for understanding how communities and ecosystems respond to both anthropogenic and ecological perturbations. Studying invasive populations both in the field (Burnett & Moulton, 2015) and out (Allen & Burnett, in prep.; Burnett *et al.*, in review, 2017, 2018; Donovan *et al.*, 2018), coupled with past field experience (Burnett & Moulton, 2015; Burnett & Sieving, 2016) led to my deep appreciation for the amount of time, energy, and monetary resources required to design and conduct field studies and monitoring programs.

**II. Dissertation research overview: ecological regime shift detection methods**

Abrupt changes to the feedbacks regulating environmental conditions can trigger non-linear, unexpected, and undesirable responses, or “**regime shifts**”. Alarming examples of regime shifts in response to anthropogenic forcing include widespread insect declines, loss of faunal biodiversity, and an increase in the frequency and intensity of extreme weather events. Forecasting potential regime shifts becomes increasingly important. Scientists propose many statistical and numerical approaches as leading indicators of these regime shifts. However, these do not consistently detect regime shifts in complex, high dimensional ecological systems.

My dissertation research focuses on developing and refining the methods used to detect ecological regime shifts. In addition to rigorously testing these proposed methods, I also introduce a novel approach for detecting quick changes in abrupt systems (see Burnett & Price, 2018). This research addresses an urgent need to develop accessible tools for identifying and predicting such shifts on the landscape.

**III. Other collaborative research efforts**

In addition to encouraging broad-scale research using extant data, synthesis science is largely driven by collaborative efforts. Adopting this philosophy during my tenure as a Ph.D. student allowed me to gain exposure to explore new topics (Allen *et al.*, 2016; Chuang *et al.*, 2018) while still building upon my expertise in avian ecology (Allen & Burnett, in prep.; Burnett *et al.*, in prep., 2017; La Sorte *et al.*, 2018).

**IV. The POE as a catalyst for my professional development as a quantitative ecologist**

This fellowship will provide a valuable opportunity to conduct independent research *and* gain valuable teaching experience and skills. Working closely with Dr. Tenhumberg to achieve the aims proposed in this project will improve upon the skills I believe are essential to be a successful quantitative ecologist, including (i) an advanced proficiency in matrix and stochastic population modelling techniques and (ii) effectively communicating quantitative studies to the discipline in high-impact forums.

Using full-annual-cycle integrated population models to identify impacts of climate change on bird population dynamics

POE Fellow: Jessica L. Burnett

Faculty Sponsor: Brigitte Tenhumberg

**Anticipated project dates** 01 September 2019 - 31 August 2021

**I. Introduction**

Measurable effects of global climate change on both ecological and evolutionary processes governing the large-scale distribution and population trends of birds have already been documented. These effects include species-wide poleward range shifts (Both *et al.*, 2004; La Sorte & Thompson, 2007) and altered phenological patterns (Charmantier & Gienapp, 2014), and can manifest as both direct (e.g., immediate death upon extreme weather event) and indirect effects (e.g. carryover effects—nonlethal, impacts fitness in the following season or stage). Understanding how a species responds to various environmental drivers associated with climate change will provide insight into population dynamics and allow for more precise projections over space and time.

Mathematical modelling is an important tool for understanding consequences of climate change on bird species and populations. Integrated population models (IPMs) are an approach to combining both count and demographic data to build a single model for projecting population dynamics and estimating parameters (Besbeas *et al.*, 2002; Freeman & Crick, 2003; Schaub & Abadi, 2011). IPMs are unique in a few ways. First, the framework allows for estimation of latent parameters. Second, combining demographic and abundance data improve precision of parameter estimates--this is especially useful when one or more of the datasets in question are of low quality. Third, incorporating multiple data types allows us to account for variation in the observation process (e.g., recapture rate, observer naivety) among relevant stages (e.g., age, sex, season). Finally, the IPM framework allows the user to combine well-developed and heavily scrutinized models designed for individual datasets [e.g., the Link-Sauer model for analysing Breeding Bird Survey count data, Sauer & Link, (2011)]. Although a seemingly powerful tool for wildlife conservation and research, IPM in the ecological literature is largely restricted to studies which advance the methods rather than ask ecological questions (Schaub & Abadi, 2011). We will examine the impacts of climate change on the population dynamics and vital rates for birds within an IPM framework. This project has two major components:

1. *Full-annual-cycle integrated population model:* Build a stochastic, two-season, stage-structured matrix population model to estimate population dynamics and demographic parameters by incorporating multiple data types from independent monitoring schemes.
2. *Time-lagged effects of climate on population dynamics:* Identify time-lagged relationships among weather and extreme weather events and population dynamics and demographic parameters (Tenhumberg *et al.*, 2018)

The POE fellow and sponsor have the expertise required to achieve the aims of this project (see also: Research Statement): (a) disciplinary expertise in avian ecology (Burnett & Sieving, 2016; La Sorte *et al.*, 2018), population ecology (e.g., Tenhumberg *et al.*, 2009; Burnett & Moulton, 2015; Burnett *et al.*, 2017), stage structured population modelling (e.g. Haridas *et al.*, 2016; Werle *et al.*, 2017) and quantifying drivers of population dynamics (e.g., Tenhumberg *et al.*, 2015; Eager *et al.*, 2017), and (b) advanced proficiency in scientific computing (JLB and BT). The project can be strengthened by departmental (e.g., macroecology—Lyons; community ecology—Russo; Bayesian modelling—Brassil) and inter-departmental (e.g., Rebarber, Department of Mathematics) collaborations.

In addition to advancing our understanding of population-climate change dynamics, this work advances Open Science and encourages the reuse and integration of disparate, publicly-funded data to advance scientific understanding.

**II. Data**

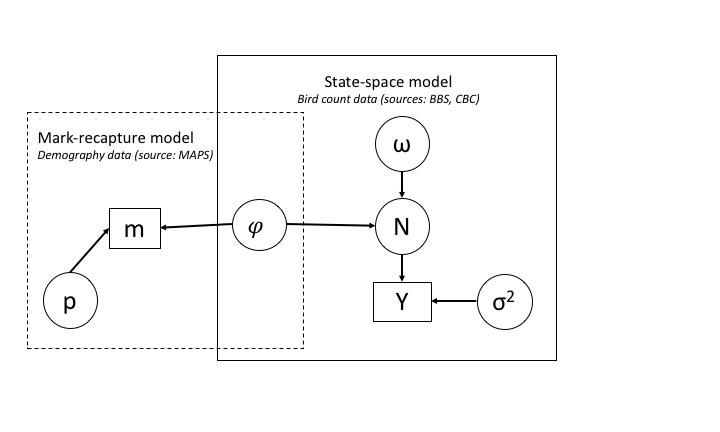
We will use data from three long-term and widespread avian monitoring programs: (1) North American Breeding Bird Survey (BBS), abundance estimates during the breeding season; (2) Christmas Bird Count (CBC), winter bird count estimates in winter; and (3) the Mapping Avian Productivity and Survival (MAPS) program, vital rates of marked and recaptured individuals. The BBS and CBC are long-term population monitoring programs of breeding birds and wintering birds, respectively, in Mexico, the U.S., and Canada. These data comprise abundance indices and therefore do not allow for estimation of vital rate parameters. The MAPS program was designed to complement the BBS in that individual-level observations allow for estimation of vital rates.

Although the count and demographic data provide weather information, they are insufficient as indices of within-season and intra-annual climate. We will therefore incorporate additional climate and weather data sources for intra-annual modelling to inform our model. We will use open access, site-level weather data (e.g., National Oceanic and Atmospheric Administration) and land use maps (e.g., U.S. Land Cover Institute).

**III. Build the base model: a full-annual-cycle integrated population model (FAC-IPM)**

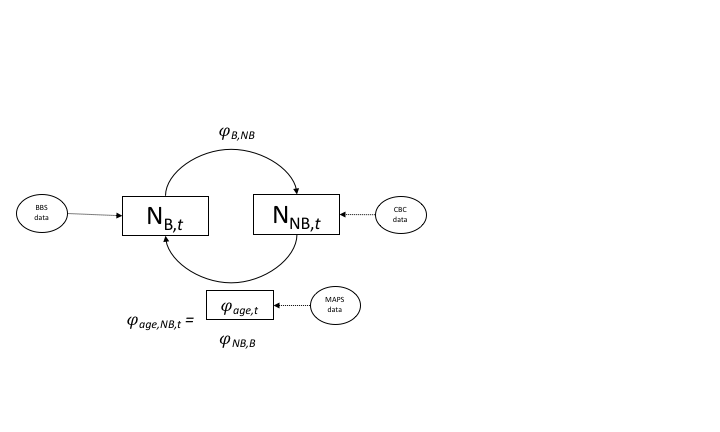
The increasing breadth and quality of long-term monitoring data provides a valuable opportunity to develop models of complex population dynamics by explicitly integrating individual-level observations of vital rates. Only recently have counts from multiple seasons been incorporated into IPMs in wildlife modelling. However, these studies (Fink *et al.*, 2018; Robinson *et al.*, 2018), used count data from a single resource, eBird (Sullivan *et al.*, 2009). Because eBird data are collected opportunistically by citizen scientists, more structured monitoring data may provide more reliable indices of population abundance.

*Fig. 1. Stylized directed acyclic diagram depicting the mark-recapture and state-space model components of the FAC-IPM. Boxes indicate observations and circles parameters estimated from data*. *Here, p = recapture probability; = apparent survival rate; m = individual-based observations; σ2 = observation error; ω = immigration; N = true population abundance; Y = observed population abundance.*



*Two-season, two-stage integrated population model.* We will develop an integrated population model (Fig. 1) for select non-migratory (permanent resident) birds whose ranges are largely restricted to the continental United States (e.g., Northern Cardinal, House Finch). Integrating three datasets, we will simultaneously estimate abundance and demographic rates. Survival (*p*) will be estimated from demographic and count data, population size (N) will be estimated for the breeding (BBS data) and non-breeding (CBC data) seasons.

State-space models comprise both process and observer components, which are ideal for accounting for biases and error inherent in human censusing (imperfect detection) of fauna. Full-annual-cycle bird population models incorporate intra-annual stages or seasons into the population model. The fully integrated model will incorporate two count datasets spanning two seasons (the full-annual-cycle), one for the breeding (BBS) and one for non-breeding (CBC) seasons and the demographic data (MAPS), also spanning two seasons (Fig. 2). We will use a discrete time (bi-annual) model with age (hatch vs. after hatch year) and seasonal (breeding vs. non-breeding) structure. We will modify the hierarchical models described in Ahrestani *et al.* (2017a) and Link & Sauer (2007) to estimate NB and B, and NNB and NB, respectively. We will fit the model with a Bayesian framework, and assuming a first-order Markov process we will fit the model using MCMC methods.



*Fig. 2. Alternative description of the IPM, indicating both the hierarchical structure of and data sources used to estimate apparent survival (), population size in the breeding (N­­B,t.) and non-breeding (N­­NB,t.) seasons, survival probability . Parameters estimated (boxes) from data sources (ovals) are indicated. Model parameters are indexed by age (hatch vs. after hatch year) and time (t).*

**V. Identifying time-lagged impacts of weather and climate on bird population dynamics**

Climate change models predict both a change in climate (long-term mean weather conditions) and an increase in the climatic variance, including extreme weather events. Using a modelling approach similar to that of Tenhumberg *et al.* (2018), we will incorporate climatic information into our FAC-IPM (describe in **III.**)to not only quantify the impacts of climate change on population dynamics, but also to determine the spatial and temporal scales at which climate has a lagged-effect. Each dataset used to build our FAC-IPM (BBS, CBC, MAPS) contains site-level information, including spatial locations. This enables us to capture the spatially-induced variation in demographic parameters and weather covariates while simultaneous exploring the influence of time-lags on population dynamics. Importantly, incorporating a spatial component into the IPM framework allows us to interpolate species distribution across space-time (i.e. build species distribution models).

**VI.** **Expected results and products**

*Research articles.* We expect each project component (**III.** and **IV.**) to culminate in a high-quality publication.

*Working groups.* Integrated modelling efforts are aided when eliciting expert advice from those who work daily with the data and systems used in the analysis. Although this project will focus on only a few species, it lends itself well to creating a flexible program by which other species can be modelled. The POE fellow will coordinate proposals for a synthesis working group (at, e.g., USGS Powell Center, NimBios, iDiv) to explore further the challenges and opportunities with integrated population modelling herein and elsewhere (Hostetler *et al.*, 2015; Ahrestani *et al.*, 2017; Arnold *et al.*, 2018; Fink *et al.*, 2018; Zipkin & Saunders, 2018).

**VII. Teaching**

The POE fellow has experience hosting workshops on statistical programming, data analysis, and data visualization, but has yet to design and implement a semester-long course. This fellowship provides a rare and valuable opportunity to practice pedagogy. With the interests of the students in mind, the POE fellow will offer a 1-hour seminar/discussion-based course exploring and critiquing Integrated Population Models. When possible, the POE will also contribute lessons and/or modules to existing courses on the topics of IPM, invasion, urban and avian ecology, and population ecology.

**Literature Cited**

Ahrestani, F.S., Saracco, J.F., Sauer, J.R., Pardieck, K.L. & Royle, J.A. (2017a) An integrated population model for bird monitoring in North America. *Ecological Applications*, **27**, 916–924.

Ahrestani, F.S., Saracco, J.F., Sauer, J.R., Pardieck, K.L. & Royle, J.A. (2017b) An integrated population model for bird monitoring in North America. *Ecological Applications*, **27**, 916–924.

Allen, C.R., Birge, H.E., Bartelt-Hunt, S., Bevans, R.A., Burnett, J.L., Cosens, B.A., Cai, X., Garmestani, A.S., Linkov, I., Scott, E.A., Solomon, M.D. & Uden, D.R. (2016) Avoiding Decline: Fostering Resilience and Sustainability in Midsize Cities. *Sustainability*, **8**, 844.

Allen, C.R. & Burnett, J.L. (in prep.) *Avian invaders’ biogeography and emerging invasive species in North America*. *Global avian invasions*, CABI.

Arnold, T.W., Clark, R.G., Koons, D.N. & Schaub, M. (2018) Integrated population models facilitate ecological understanding and improved management decisions. *The Journal of Wildlife Management*, **82**, 266–274.

Besbeas, P., Freeman, S.N., Morgan, B.J. & Catchpole, E.A. (2002) Integrating mark–recapture–recovery and census data to estimate animal abundance and demographic parameters. *Biometrics*, **58**, 540–547.

Burnett, J. & Moulton, M. (2015) Recent trends in House Sparrow (Passer domesticus) distribution and abundance in Gainesville, Alachua County, Florida. *Florida Field Naturalist*, **43**, 167–172.

Burnett, J.L., Pope, K., L., Wong, A., Allen, C.R., Haak, D.M., Stephen, B.J. & Uden, D.R. (2018) Thermal Tolerance Limits of the Chinese Mystery Snail (Bellamya chinensis): Implications for Management. *American Malacological Bulletin*, **36**, 140–144.

Burnett, J.L. & Price, N.B. (2018) R package for calculating distance traveled in community time series.

Burnett, J.L., Price, N.B., Tyre, A.J., Hefley, T.J., Allen, C.R., Angeler, D.G. & Twidwell, D. (in prep.) A guide to Fisher Information for ecologists.

Burnett, J.L., Roberts, C.P., Allen, C.R., Brown, M.B. & Moulton, M.P. (2017) Range expansion by Passer montanus in North America. *Biological invasions*, **19**, 5–9.

Burnett, J.L. & Sieving, K. (2016) Songbird distress calls as an improved method for detecting Red-shouldered Hawks (Buteo lineatus). *Florida Field Naturalist*, **44**, 157–168.

Burnett, J.L., Wilcox, R.C., Stephen, B.J., Uden, D.R., Allen, C.R., Freeman, P.W. & Pope, K.L. (in review) Shell strength does not limit predation of an invasive snail species (Bellamya chinensis) by native fish. *Journal of Freshwater Ecology*.

Burnett, J.L., Wszola, L., Mirochnitchenko, Stuber, E., Bomberger Brown, Mary, Allen, Craig R., Twidwell, Dirac & Carroll, John (in prep.) Large-sacle crop patterns influence Gray Partridge (Perdix perdix) site occupancy in North America.

Carpenter, S.R., Armbrust, E.V., Arzberger, P.W., Chapin, F.S., Elser, J.J., Hackett, E.J., Ives, A.R., Kareiva, P.M., Leibold, M.A., Lundberg, P., Mangel, M., Merchant, N., Murdoch, W.W., Palmer, M.A., Peters, D.P.C., Pickett, S.T.A., Smith, K.K., Wall, D.H. & Zimmerman, A.S. (2009) Accelerate Synthesis in Ecology and Environmental Sciences. *BioScience*, **59**, 699–701.

Charmantier, A. & Gienapp, P. (2014) Climate change and timing of avian breeding and migration: evolutionary versus plastic changes. *Evolutionary Applications*, **7**, 15–28.

Chuang, W.C., Garmestani, A., Eason, T.N., Spanbauer, T.L., Fried-Petersen, H.B., Roberts, C.P., Sundstrom, S.M., Burnett, J.L., Angeler, D.G., Chaffin, B.C., Gunderson, L., Twidwell, D. & Allen, C.R. (2018) Enhancing quantitative approaches for assessing community resilience. *Journal of Environmental Management*, **213**, 353–362.

Donovan, V.M., Burnett, J.L., Bielski, C.H., Birgé, H.E., Bevans, R., Twidwell, D. & Allen, C.R. (2018) Social–ecological landscape patterns predict woody encroachment from native tree plantings in a temperate grassland. *Ecology and evolution*.

Eager, E.A., Pilson, D., Alexander, H.M. & Tenhumberg, B. (2017) Assessing the influence of temporal autocorrelations on the population dynamics of a disturbance specialist plant population in a random environment. *The American Naturalist*, **190**, 570–583.

Fink, D., Auer, T., Ruiz-Gutierrez, V., Hochachka, W.M., Johnston, A., La Sorte, F.A. & Kelling, S. (2018) Modeling Avian Full Annual Cycle Distribution and Population Trends with Citizen Science Data. *bioRxiv*, 251868.

Freeman, S.N. & Crick, H.Q.P. (2003) The decline of the Spotted Flycatcher Muscicapa striata in the UK: an integrated population model. *Ibis*, **145**, 400–412.

Haridas, C.V., Meinke, L.J., Hibbard, B.E., Siegfried, B.D. & Tenhumberg, B. (2016) Effects of temporal variation in temperature and density dependence on insect population dynamics. *Ecosphere*, **7**, e01287.

Hostetler, J.A., Sillett, T.S. & Marra, P.P. (2015) Full-annual-cycle population models for migratory birds. *The Auk*, **132**, 433–449.

La Sorte, F.A., Lepczyk, C.A., Burnett, J.L., Hurlbert, A.H., Tingley, M.W. & Zuckerberg, B. (2018) Opportunities and challenges for big data ornithology. *The Condor*, **120**, 414–426.

La Sorte, F.A. & Thompson, F.R.T. (2007) Poleward shifts in winter ranges of North American birds. *Ecology*, **88**, 1803–1812.

Link, W.A. & Sauer, J.R. (2007) Seasonal Components of Avian Population Change: Joint Analysis of Two Large-Scale Monitoring Programs. *Ecology*, **88**, 49–55.

Robinson, O.J., Ruiz-Gutierrez, V., Fink, D., Meese, R.J., Holyoak, M. & Cooch, E.G. (2018) Using citizen science data in integrated population models to inform conservation. *Biological Conservation*, **227**, 361–368.

Sauer, J.R. & Link, W.A. (2011) Analysis of the North American breeding bird survey using hierarchical models. *The Auk*, **128**, 87–98.

Schaub, M. & Abadi, F. (2011) Integrated population models: a novel analysis framework for deeper insights into population dynamics. *Journal of Ornithology*, **152**, 227–237.

Sullivan, B.L., Wood, C.L., Iliff, M.J., Bonney, R.E., Fink, D. & Kelling, S. (2009) eBird: A citizen-based bird observation network in the biological sciences. *Biological Conservation*, **142**, 2282–2292.

Tenhumberg, B., Crone, E.E., Ramula, S. & Tyre, A.J. (2018) Time-lagged effects of weather on plant demography: drought and *Astragalus scaphoides*. *Ecology*, **99**, 915–925.

Tenhumberg, B., Suwa, T., Tyre, A.J., Russell, F.L. & Louda, S.M. (2015) Integral projection models show exotic thistle is more limited than native thistle by ambient competition and herbivory. *Ecosphere*, **6**, art69.

Tenhumberg, B., Tyre, A.J. & Rebarber, R. (2009) Model complexity affects transient population dynamics following a dispersal event: a case study with pea aphids. *Ecology*, **90**, 1878–1890.

Werle, R., Tenhumberg, B. & Lindquist, J.L. (2017) Modeling shattercane dynamics in herbicide-tolerant grain sorghum cropping systems. *Ecological Modelling*, **343**, 131–141.

Zipkin, E.F. & Saunders, S.P. (2018) Synthesizing multiple data types for biological conservation using integrated population models. *Biological Conservation*, **217**, 240–250.